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Determining In-Flight Tracker Accuracy

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Determining In-Flight Tracker Accuracy

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ABSTRACT

Evaluating a system in flight poses challenges that are not found in a laboratory type environment. This paper discusses some of the issues in conducting an in-flight test to evaluate tracker accuracy, such as head movement, synchronization of time, changing coordinate systems and interpolating data. The paper's technical approach outlines one possible solution to deal with in-flight challenges.

Keywords: Helmet-mounted tracker, helmet-mounted tracker accuracy, tracker accuracy

1. INTRODUCTION

In this paper we begin by discussing different types of head tracker accuracy. In general, as the level of realism increases in the type of accuracy, the difficulty in determining that accuracy also increases. We present different types of accuracy and describe a previous effort in determining accuracy on the ground. We use the previous effort to help set up our own ground test before we focus on conducting an in-flight test. We use two aircraft and a head tracking system to collect data, and then we compare the head tracker data with attitude and position data. A portion of our analysis is focused on understanding possible sources of error and deciding test methodologies to minimize that error.

The type of accuracy that is found in a test should be based upon the required realism. While adding realism to a test makes it more relevant to operations, it is usually traded off by an increase in the difficulty of setting up the test and the introduction of error. Note that random measurement error is increased variability around a mean value, while systematic measurement error is a shift in the mean value. Obviously, a more accurate head tracker will have less random and systematic errors.

As a background, we define six types of accuracy: lab static, lab dynamic, installed static, installed dynamic, operational static and operational dynamic[2]. Lab static accuracy is found by conducting the test in a controlled laboratory environment, where the head tracker and target are mounted to permanent fixtures. Specialized equipment, which can be calibrated, is used to perform precise measurements. Finding lab static accuracy is useful as a test to gain an initial insight into a head tracker's properties, so a decision can be made on continuing the effort to find additional types of accuracy or to stop and modify the head tracker. Lab dynamic accuracy is an extension of lab static accuracy, with the difference being that either the head tracker or the target is moved in a smooth predictable manner. The next higher level of realism is installed static accuracy. This is where the pilot is wearing the head tracker in the cockpit while the aircraft is stationary on the ground. The target is also a fixed point on the ground. The pilot's inability to keep the head perfectly still introduces random measurement error, in addition to the systematic measurement error that is also found in the laboratory environment. Installed dynamic introduces a moving target. Operational static accuracy is found by testing the head tracker in a flying aircraft. In order for this accuracy to be defined as static, the aircraft should be in straight, level and unaccelerated flight and the target aircraft should remain stationary relative to the aircraft with the head tracker under test. The highest level of realism is operational dynamic accuracy. This represents an aircraft performing its actual mission. As will be explained later, finding accuracy in flight adds significant amount of systematic and random measurement error.

Vince Parisi describes a method to find installed static accuracy using a ground test[3]. Because the test was conducted in a hangar, he had much control over the experiment. He took care to keep the aircraft motionless by stabilizing it with jacks and laser surveying all target points, including the position of the aircraft. What made the test installed was that he let the pilot aim the head tracker, instead of mounting it on a stand.

2. Determining Installed and Operational Static Accuracies

We now explain how we set up two tests to find installed and operational static accuracies. We use a ground test to find installed accuracy and conduct an in-flight test to find operational static accuracy. We also use the ground test as a verification of our methods and the results become a baseline for finding operational static accuracy. For most of our data points, we use two fighter aircraft. To avoid confusion, we call the aircraft with the head tracker system under evaluation the "test" aircraft and the aircraft that is being targeted the "target" aircraft.

2.1 Equipment

For the ground test, the test aircraft is a fighter aircraft outfitted with a GPS pod. The target aircraft is another fighter aircraft, also with an attached GPS pod. We survey a runway windsock to serve as an additional target. The runway windsock fits our purpose well because it is easy to see and is unlikely to be moved. In several data points, we park the aircraft on a surveyed point and have the pilot target the windsock to serve as a baseline in understanding error attributed to the GPS pods. The in-flight test requires the same equipment as conducting the ground test with two aircraft.

2.2 Data

We have four sources of data. The first two sources are from the two GPS pods (or the constant surveyed points). Data are output from the GPS pods as longitude and latitude location and altitude information based upon an elliptical mathematical model of the earth. Using this model of the earth, the data are converted into Cartesian coordinates with an arbitrary origin on the test range. The third source is from the head tracker, which represents line-of-sight data to know where the head is looking. Line-of-sight data are composed of elevation angle, azimuth angle, roll angle, and position in cockpit with respect to the design eye location. The final source of data is aircraft attitude data. While less critical for the ground test, it still allows us to know the location of the design eye relative to the GPS pod or surveyed point. In-flight attitude data allow us to know the location of the design eye in a dynamic environment. All data sources have their own associated time field that allows us to combine them for analysis. For this to be possible, the times are synchronized, based on Inter-Range Instrumentation Group (IRIG) standards.

2.3 Method

While on the ground, we simply have the pilot look at the target. Using a wrist watch synchronized to IRIG time, we write down the time interval of when the pilot is looking at the target. This allows us to know which data points to use in the analysis. To minimize problems in the in-flight test, we conduct a dry run for the in-flight test as a part of our ground test. The in-flight test has the pilot of the test aircraft looking at the target aircraft from a wide range of azimuth and elevation angles. Table 1 shows the 36 points that we use. While we cannot simulate the elevation angles in the ground test, we have the test aircraft "drive" around on the runway to get the same azimuth angles as the in-flight test. The ground test begins with the test aircraft on a surveyed point, where the pilot will look at both a stationary target aircraft and the windsock. The test aircraft also targets the windsock in the in-flight test as a way to create a baseline for measuring the head tracker accuracy in an air-to-ground targeting situation and to understand the inherent inaccuracy of the GPS pods. In both the ground and in-flight tests, we use the light on the vertical tail of the target aircraft as the targeting point. The light can be seen from most angles and is also visible at night.

Test Points			Elevation of Target relative to Test (degrees)			
1-4	Azimuth of Target relative to Test (e.g., 90°=3 o'clock)	0	0	30	60	-30
5-8		30	0	30	60	-30
9-12		60	0	30	60	-30
13-16		90	0	30	60	-30
17-20		120	0	30	60	-30
21-24		-120	0	30	60	-30
25-28		-90	0	30	60	-30
29-32		-60	0	30	60	-30
33-36		-30	0	30	60	-30

Table 1. In-Flight Test Data Points

3. Data Analysis

In order to find accuracy, we compare the line of sight (LOS) vector of the head tracker with the vector originating from the test aircraft that ends at the target aircraft based upon the position data of the two aircraft. While this approach is straightforward, there are numerous issues that can cause measurement error. After presenting our approach, we describe some of the issues and how we try to minimize the error that they cause.

3.1 Approach

We begin by establishing the three reference frames used in our analysis. We have the range reference frame, which is an orthogonal reference frame established in the vicinity of the test area. It is oriented parallel to the earth's local reference frame, where x, y and z are North/South, East/West and up/down, respectively. Establishing the range reference frame simplifies calculations by eliminating the need to use latitude and longitude values. The second reference frame is that of the test aircraft, and it is aligned with the test aircraft's longitudinal axis (x, with positive forward), its lateral axis (y, with its positive out the right) and its vertical axis (z, with its positive down). The final reference frame is the tracker reference frame which is aligned along the tracker's LOS.

We have three data types that use the three reference frames. The first data type is the vector from the test aircraft to the target aircraft with respect to the range reference frame, written as $V_{Tgt:Tst\ (earth\ rf)}$. The second data type is the orientation of the test aircraft with respect to the range reference frame and is denoted by the angles ψ, θ and φ, which are the negative values of aircraft heading, pitch and roll, respectively. Finally, we have the orientation of the tracker's LOS with respect to the test aircraft reference frame, written as $V_{HMD:Tst\ (Tst\ rf)}$. We find the accuracy of the tracker by comparing the two vectors $V_{Tgt:Tst\ (earth\ rf)}$ and $V_{HMD:Tst\ (Tst\ rf)}$, so they must be in the same reference frame. We choose to use the test aircraft reference frame as the common reference frame so we can relate to the perspective of the test aircraft pilot. Because the tracker data are already given with respect to the test aircraft reference frame, we only need to find $V_{Tgt:Tst\ (earth\ rf)}$ with respect the test aircraft reference frame, with the resulting vector written as $V_{Tgt:Tst\ (Tst\ rf)}$. This is done by rotating $V_{Tgt:Tst\ (earth\ rf)}$ through the negative angles of the test aircraft's orientation with respect to the range reference frame.

$$\begin{bmatrix} u_{p'} \\ v_{p'} \\ w_{p'} \end{bmatrix} = \begin{bmatrix} \cos(\theta)\cdot\cos(\psi) & \cos(\theta)\cdot\sin(\psi) & -\sin(\theta) \\ -\cos(\theta)\cdot\sin(\psi)+\sin(\phi)\cdot\sin(\theta)\cdot\cos(\psi) & \cos(\phi)\cdot\cos(\psi)+\sin(\phi)\cdot\sin(\theta)\cdot\sin(\psi) & \sin(\phi)\cdot\cos(\theta) \\ \sin(\phi)\cdot\sin(\psi)+\cos(\phi)\cdot\sin(\theta)\cdot\cos(\psi) & -\sin(\phi)\cdot\cos(\psi)+\cos(\phi)\cdot\sin(\theta)\cdot\sin(\psi) & \cos(\phi)\cdot\cos(\theta) \end{bmatrix} \begin{bmatrix} u_p \\ v_p \\ w_p \end{bmatrix}$$

Equation 1. Aircraft Rotation Sequence for transforming $V_{Tst:Erth\ (earth\ rf)}$ into $V_{Tgt:Tst(Tst\ rf)}$

The unit vector $\begin{bmatrix} u_p \\ v_p \\ w_p \end{bmatrix}$ is the component values of $V_{Tgt:Tst\ (earth\ rf)}$ and the unit vector $\begin{bmatrix} u_{p'} \\ v_{p'} \\ w_{p'} \end{bmatrix}$ is the component values of $V_{Tgt:Tst\ (Tst\ rf)}$. We also use the unit vector associated with $V_{HMD:Tst\ (Tst\ rf)}$, which can be found by calculating the unit vector from the tracker azimuth, elevation and roll values or by using the tracker's reported direction cosines, if available. This unit vector's components are written as $\begin{bmatrix} u_t \\ v_t \\ w_t \end{bmatrix}$. Finally, we can determine the error angle between the position and LOS unit vectors using Equation 2.

$$\theta_{error} = \cos^{-1}\left(u_{p'} \cdot u_t + v_{p'} \cdot v_t + w_{p'} \cdot w_t\right)$$

Equation 2. Calculating the Angle between Position and Line-Of-Sight Unit Vectors

We program the equations in Excel® using Visual Basic®. Because data are output from the aircraft, head tracker and GPS pods in discrete time intervals, we must interpolate the different data sources to match up the intervals. Depending on the aircraft, the time between attitude data points is approximately 30 milliseconds, the time between the head tracker data points is approximately 20 milliseconds and the time between the GPS pod data points is 100 milliseconds. We interpolate from higher to lower frequency so we make fewer assumptions on the missing data points. Therefore, we first interpolate the head tracker data to fit the times of the aircraft data and then we interpolate the aircraft and head tracker data to match the times of the GPS data. We use PERL to program the interpolation code.

3.2 Data Issues

Deciding how far apart to place the test and target aircraft is a trade-off. For far distances, we have imprecision because the test aircraft pilot is unable to pick out a small point on the target aircraft. For near distances, we also have imprecision due to measurement error in the GPS system. In Figure 1, the point of interest is the top of the vertical stabilizer of the target aircraft. Now suppose that the GPS system miscalculates the top of the vertical stabilizer to be the nose of the target aircraft, while the head tracker is perfectly accurate in determining the top of the vertical stabilizer. Because angle B is obviously larger than angle A, the GPS system error causes more error in the angle between the two aircraft when the aircraft are in closer proximity. A reasonable approach is to set the distance between the two aircraft such that the GPS system measurement error is an acceptable order of magnitude smaller than the head tracker error. The ground test is useful in determining the GPS system and head tracker errors. In our case, we set the aircraft to be about 3200 feet apart, which gives us a GPS measurement error of about 2 milliradians. An additional method to reduce error is to ensure that the target location on the target aircraft is very noticeable. We use the vertical stabilizer light, because it is easy to see at night, dusk, and dawn.

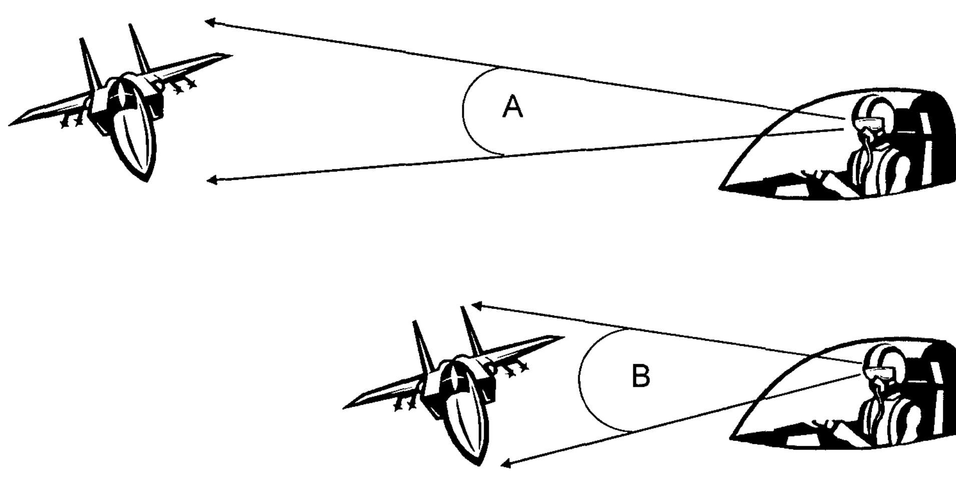

Figure 1. The Effect of Distance on GPS System Measurement Error

Aircraft vibration and aircraft flex are sources of measurement error, especially during the in-flight test. These errors are nearly impossible to control when finding operational static accuracy for aircraft. By assuming that these errors follow a normal distribution, we average JHMCS and attitude data values over a time interval of 15 or more data points. This average value should be closer to the actual value.

The positions of GPS satellites must be known in order to triangulate the position of a receiver on earth. Because satellites do not travel perfectly known paths, the paths must be estimated using an atomic clock on the satellite and an algorithm on the ground[4]. While an atomic clock is one of the most accurate timepieces, the internal GPS satellite clocks are less accurate than modern atomic clocks and their lack of precision can cause error greater than the accuracy of most head trackers. We overcome this by differentially correcting the GPS pod data with data from precisely located ground points, which removes much of the systematic error.

Because GPS satellites have atomic clocks, their time is relatively accurate compared to the earth's inconsistent rotation and orbit, so GPS pod data time needs to be corrected for this inconsistency that has accumulated since the first GPS satellite launch in 1978. In our case, GPS pod data time is "off" by approximately 14 seconds, which is corrected by a simple translation in the GPS pod data times.

4. Conclusion

This paper describes six types of accuracy: lab static, lab dynamic, installed static, installed dynamic, operational static and operational dynamic. In general, as the realism of the accuracy increases, the difficulty in setting up a test to find the accuracy also increases. We present one possible method of finding installed static and operational static accuracies. The calculations are straight forward, but data issues that cause measurement error, such as vibration and synchronization of time, must be dealt with.

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